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DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES AT ELEVATED TEMPERATURES

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U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

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DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES AT ELEVATED TEMPERATURES

Thomas Collins

Isidore Bady

DA TASK NR 3A99-15-001-01

Abstract

Measurements were made of the real part of the dielectric constant and loss tangent of 32 commercial ferrites at x-band at temperatures from 25 C to 250 C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the diameter and real part of the dielectric constant. For a sample diameter of 35 mils, the correction ranged from 4 to 10% for dielectric constants of 7 to 16, respectively. Expressions were also derived for the correction due to the contribution of the irises and metal losses to the cavity Q, since the resonant frequency of the cavity changed when a sample was introduced.

The accuracy in the measurement of the real part of the dielectric constant is ± 3%, where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005.

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FIGURES

DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES AT ELEVATED TEMPERATURES

INTRODUCTION

The dielectric properties of ferrites play an important role in the behavior of ferrites in microwave devices. Since the dielectric properties of ferrites are affected by temperature, a study was undertaken to determine the variation of the dielectric constant of a large number of commercial ferrites. The temperature range covered was from room temperature to 250°C, but not exceeding the curie temperature. The samples tested were commercially available at the time they were obtained from several commercial suppliers.

The dielectric constant of ferrites is a complex quantity, as shown in Eq. (1).

$$K = K' - jK'' \tag{1}$$

K' is the real part of the dielectric constant, and K'' the imaginary, or dissipative part. The dielectric loss tangent is defined in Eq. (2).

$$\tan \delta = K''/K'. \tag{2}$$

The dielectric loss tangent is also called the dissipation factor.

GENERAL TEST METHOD

Measurements were made using a resonant cavity and the perturbation theory, as described by Artman and Tannenwald.[1] This method is also the basis of the "Proposed Method of Test for Complex Dielectric Constant of Nonmetallic Magnetic Materials at Microwave Frequencies," now being prepared by a task group of the American Society for Testing Materials (ASTM). A block diagram of the equipment used is shown in Fig. 1.

The test frequency was approximately 9.4 gigacycles. The samples were in the shape of rods approximately 0.035 inch in diameter and 1¼ inches long. All frequency measurements were made using a frequency counter that measured a known subharmonic of the actual frequency.

TEST RESULTS

Test results for the real part of the dielectric constant, K', are shown in Table I. At 25°C the actual value of K' is given. At other temperatures, the ratio of K' at that temperature to K' at 25°C is given.

Table I shows that the real part of the dielectric constant generally increased with temperature. The increase, however, was quite small. Sample 1 showed the maximum increase; at 250°C this amounted to 6.2%, which corresponds to a temperature coefficient of approximately 300 parts per million per degree centigrade.

Test results for tan δ are shown in Table II. For most samples, tan δ increased with increasing temperature. Several cases of tan δ decreasing with temperature were noted. These decreases are fairly small and may be due to measurement error.

The composition of the samples and the values of saturation magnetization ($4\pi M_s$) were obtained from the manufacturer's data. The composition gives only the principal elements and may not include small amounts of additives. It will be noted that in some cases there are two samples that behave quite differently, but each has the same indicated composition and very similar saturation magnetization. This could be due to differences in processing techniques and use of additives as practiced by different manufacturers.

DISCUSSION OF TEST METHOD

Formulas Based on Perturbation Theory

In measuring the dielectric constant of the ferrite, the resonant frequency and loss tangent of the empty cavity, and of the cavity with the sample, are determined. By using subscript 1 to denote measurements made on the empty cavity and subscript 2 to denote measurements made on the cavity with the sample, we obtain

$$\frac{F_1 - F_2}{F_1} = 2(K' - 1)\frac{V_s}{V_c} \tag{3}$$

$$(\tan \delta_L)_2 - (\tan \delta_L)_1 = 4K''\frac{V_s}{V_c} \tag{4}$$

where V_s and V_c are the volume of the sample and cavity, respectively, and tan δ_L is the (loaded) loss tangent of the cavity. K' and K'' can be readily determined from the above.

The loaded loss tangent of a cavity is measured by determining the two frequencies, F_h and F_ℓ, on either side of the resonant frequency, F_r, at which the output of the cavity drops by α db. Thus

$$\tan \delta_L = \frac{F_h - F_\ell)}{F_r \sqrt{10^{\alpha/10} - 1}} \tag{5}$$

Modifications in Perturbation Theory

1. *Effect of Sample Diameter.*

For the perturbation theory to be accurate, the sample diameter must be sufficiently small. The criteria as to when a diameter is sufficiently small will be discussed below. In practice, sample diameters in the range of 0.03 to 0.05 inch have been used by different laboratories at a test frequency in the range of 9 to 10 gigacycles. The test method for dielectric constant now being proposed by the ASTM calls for a sample diameter of 0.04 inch. As noted above, samples used in connection with this USASRDL study had diameters of approximately 0.035 inch. This value was chosen before the ASTM diameter was established.

The equivalent circuit of a dielectric post in a rectangular waveguide is given by Marcuvitz.[2] For a sample with a diameter of 0.035 inch at a frequency of 9.4 gigacycles, the sample behaves like a shunt capacitive reactance whose normalized magnitude is given in Eq. (6) below.

$$X' = 0.257\left[\frac{2\left(\frac{\lambda}{\pi d}\right)^2}{K' - 1} - 1.84\right]$$

$$= 0.257\left[\frac{261}{K' - 1} - 1.84\right] . \tag{6}$$

If the equation for shunt reactance had been derived on the basis of perturbation theory, the result would be as shown in Eq. (7).

$$X' = \frac{67.1}{K' - 1} . \tag{7}$$

Equation (6) is more accurate.

It can be shown that the error in calculating K′ using Eq. (3) is substantially the same as in calculating X′ using Eq. (7). A first-order correction to the perturbation theory can, therefore, be obtained from Eq. (6) and (7). Manipulation of these equations yields

$$\frac{(K' - 1)_T}{(K' - 1)_A} = \frac{1}{(1 + .00705\,(K' - 1)_A)} \tag{8}$$

$(K' - 1)_T$ is the true value of $(K' - 1)$. $(K' - 1)_A$ is the apparent value of $(K' - ,1)$ that would be obtained by using Eq. (3).

Equation (8) applies only for a diameter of 0.035 inch. A correction graph to cover the range of diameters actually encountered is shown in Fig. 2.

2. *Consideration of Denominator in Equation Used in Perturbation Theory*

Equation (3) shows F_1 in the denominator on the left-hand side, and this is the way the formula is generally used. However, it will now be shown that it is more accurate to use F_2. For the purpose of simplicity, this will be demonstrated on a coaxial line, as illustrated in Fig. 3. Similar results can be obtained with a rectangular waveguide.

The resonance condition is given by

$$\frac{1}{\sqrt{K'}\,\tan\,\sqrt{K'}\,\beta\,\Delta\ell} = \tan\,\beta(\ell - \Delta\ell) \tag{9}$$

where β is the phase constant in the air region. Let $\beta = \beta_o - \Delta\beta$, where β_o is the phase constant in the empty cavity at resonance.

$$\frac{1}{\sqrt{K'}\ \tan\ \sqrt{K'}\ \beta\Delta\ell} = \tan\left[\beta_o\ell - \ell\Delta\beta - \beta_o\Delta\ell + \Delta\beta\Delta\ell\right]$$

$$= \frac{1}{\tan(\ell\Delta\beta + \beta_o\Delta\ell - \Delta\beta\Delta\ell)}. \tag{10}$$

For small electrical angles, we can write as an approximation,

$$K'\beta\Delta\ell = \ell\Delta\beta + \beta_o\Delta\ell - \Delta\beta\Delta\ell \tag{11}$$

$$\frac{\Delta\beta}{\beta}\left(K' - \frac{\beta_o}{\beta}\right)\cdot\frac{\Delta\ell}{\ell}\cdot\frac{1}{1-\frac{\Delta\ell}{\ell}} \approx (K' - 1)\frac{\Delta\ell}{\ell}. \tag{12}$$

Thus, we obtain

$$\frac{F_1 - F_2}{F_2} \approx (K' - 1)\frac{\Delta\ell}{\ell} = (K' - 1)\frac{V_s}{V_c}. \tag{13}$$

It should be noted that the presence of the factor of 2 in Eq. (3) and its lack in Eq. (13) is due to the differences in the field distribution in the rectangular waveguide and in the coaxial line.

3. *Effect of Cavity Iris on Measurement of Tan δ*

According to Marcuvitz,[3] the equivalent circuit of a small iris centered in a thin, transverse, metallic plate in a rectangular waveguide is a small shunt inductor, whose normalized reactance is given by

$$X' = \frac{X}{R_o} = \frac{2\pi d^3}{3ab\,\lambda_g} = \frac{2\pi d^3 F_c}{3abV}\left[\left(\frac{F}{F_c}\right)^2 - 1\right]^{1/2}. \tag{14}$$

The meaning of a, b, d, is shown in Fig. 4A. V is the velocity of electromagnetic radiation in free space. The other terms are assumed to be known.

The equivalent circuit of a transmission line containing a cavity is shown in Fig. 4B. R_u is the resistance due to the finite resistivity of the cavity walls. Figure 4C shows the equivalent circuit of the cavity at resonance. R_s is the resistance reflected into the cavity by one of the irises. Its value is given by

$$\frac{R_s}{R_o} = R_s' = \frac{1}{R_o}\,\mathrm{Re}\left[\frac{jXR_o}{R_o + jX}\right] \approx (X')^2$$

$$= \left(\frac{2\pi d^3}{3abV}\ F_c\right)^2\left[\left(\frac{F}{F_c}\right)^2 - 1\right]. \tag{15}$$

The current in the resonant cavity is given by

$$I_o = \frac{E\frac{X}{R_o}}{R_u + 2R_s}. \tag{16}$$

The voltage across the output iris is, therefore, given by

$$E_o = XI_o = \frac{E(X^2/R_o)}{R_u + 2R_s} = \frac{ER_s}{R_u + 2R_s}. \tag{17}$$

This is also the output across the transmission line load. Since in the absence of the cavity the output voltage would have been E/2, the transmission loss T, due to the cavity, is

$$T = \frac{2R_s + R_u}{2R_s}. \tag{18}$$

Equation (18) will be used later.

Equation (15) shows that R_s is a function of frequency. Since in the process of measuring the dielectric properties of ferrites the resonant frequency of the empty cavity is different from that of the cavity with the sample in it, consideration must be given to the effect of the change in R_s on the measurement of loss tangent.

The loss tangent of a circuit element is given by the well-known equation

$$\text{Loss Tangent} = \frac{\text{energy lost per second}}{2\pi F \text{ energy stored in circuit}}. \tag{19}$$

Using the above relation, and taking into account the fact that the energy lost per second due to R_s is proportional to the square of the magnetic field at the iris, we get

$$\tan \delta_{2R_s} = C\frac{(F^2 - F_c^2)^{3/2}}{F^2}, \tag{20}$$

where $\tan \delta_{2R_s}$ is the contribution to the loss tangent of the cavity due to the iris only and C is a constant independent of frequency.

Let us define $\Delta(\tan \delta_{2R_s})$ as the difference between the value of $\tan \delta_{2R_s}$ at F_1 and its value at F_2. To a good approximation, $\Delta(\tan \delta_{2R_s})$ can be obtained by taking the differential of $\tan \delta_{2R_s}$) with respect to frequency. We then have

$$\Delta(\tan \delta_{2R_s}) = \frac{\Delta F}{F}(\tan \delta_{2R_s})\frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1}. \tag{21}$$

We want to express $\tan\ \delta_{2R_s}$ in terms of the loaded loss tangent of the cavity, $\tan\ \delta_L$. It is readily shown that

$$T = \frac{\tan\ \delta_L}{\tan\ \delta_{2R_s}}. \tag{22}$$

Using Eqs. (21) and (22), we obtain

$$\Delta(\tan\ \delta_{2R_s}) = \frac{\Delta F}{F}\ \frac{(\tan\ \delta_L)}{T} \cdot \frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1}. \tag{23}$$

Using Eqs. (3), (4), and (23) and making the approximation $K' \approx K' - 1$, it is readily shown that the error in the $\tan\ \delta$ due to the irises is given by

$$(\text{Error in } \tan\ \delta)_{2R_s} = \frac{(\tan\ \delta_L)}{2T} \cdot \frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1}. \tag{24}$$

For $F = 9.4$ gigacycles and $F_c = 6.6$ gigacycles, the above equation reduces to

$$(\text{Error in } \tan\ \delta)_{2R_s} = \frac{2}{T} \tan\ \delta_L\ . \tag{25}$$

For the cavity used in these tests, approximate values for $\tan\ \delta_L$ and T were 3×10^{-4} and 3, respectively. Thus the measured loss tangents of the samples are too high by approximately 2×10^{-4} due to the effect of the cavity irises.

4. Effect of Resistivity of Cavity Walls on Measurement of Tan δ

The frequency dependence of $\tan\ \delta_u$, the unloaded loss tangent of the empty cavity of the type used in these tests, is shown in Eq. (26).

$$\tan\ \delta_u = \frac{A(F^2 + B)}{F^{5/2}}\ . \tag{26}$$

A and B are functions of the waveguide dimensions and the intrinsic resistivity of the cavity metal. There is no need to know the value of A for the purpose of this report. The value of B for the particular cavity used in most of these tests is given later.

In these tests the resonant frequency of the cavity changed due to the insertion of the test sample; the cavity dimensions were not changed. A good approximation to the variation of $\tan\ \delta_u$ as a function of frequency under this condition can be obtained by taking the derivative of $\tan\ \delta_u$ with respect to frequency. Manipulation of Eq. (26) yields

$$\frac{\Delta(\tan\ \delta_u)}{\tan\ \delta_u} = -\frac{1}{2} \cdot \frac{\Delta F}{F} \frac{1 + 5\beta/F^2}{1 + \beta/F^2}. \tag{27}$$

At a test frequency of 9.4 gigacycles, and with the cavity used in most of our tests (TE_{101}), β/F^2 was less than 0.01. We can, therefore, write

$$\frac{\Delta(\tan\ \delta_u)}{\tan\ \delta_u} = -\frac{1}{2} \frac{\Delta F}{F}. \tag{28}$$

The above equation can be rewritten as

$$\Delta(\tan\ \delta_L) = -\frac{1}{2} \frac{\Delta F}{F} \tan\ \delta_L \left(\frac{T - 1}{T}\right). \tag{29}$$

For $\tan\ \delta_L = 3 \times 10^{-4}$ and $T = 3$, the error caused by the resistivity of the cavity walls is to make the measured loss tangent of the sample too low by approximately 0.5×10^{-4}.

In the actual calculation of the loss tangent of the samples, no corrections were made for the effects of the irises and for the effect of the resistivity of the cavity walls, since their net effect was very small.

ACCURACY

1. *Real Part of Dielectric Constant.* Measurements of the rod diameter were made with a supermicrometer. All samples had some taper along the length and some ellipticity about the cross section. It is estimated that the effective diameter was measured with an accuracy of ½%. This would contribute an error of 1% in the measurement of K′.

The resonant frequency was determined by taking the average of the two frequencies at which the output was a given fraction below the resonant output. A frequency counter was used to make all frequency measurements. A maximum error of 2% was attributed to the electrical measurement on the basis of spread in results using different cavities. The maximum overall error in measuring K′ was thus 3%.

2. *Tan δ.* As noted previously, the loss tangent of the cavity was determined by using Eq. (5). The measurement was made twice using a different value of α each time. If the two different determinations disagreed by more than 3%, additional measurements were made. A frequency counter was used in making the measurements. The maximum overall error in the loss tangent was taken as 0.0005.

REFERENCES

1. J. O. Artman and P. E. Tannenwald, "Microwave Susceptibility Measurements in Ferrites," Technical Report No. 70, MIT Lincoln Laboratory (1954).

2. N. Marcuvitz, "Wave Guide Handbook," Vol. 10, Radiation Laboratory Series, McGraw Hill (1951), p. 266.

3. Ibid, p. 238.

TABLE I
K' AS A FUNCTION OF TEMPERATURE

Sample	Composition	$4\pi M_s$*	25°C K'	100°C Ratio	150°C Ratio	200°C Ratio	250°C Ratio
1	Ni	3300	12.5	1.013	1.027	1.036	1.062
2	NiCo	3150	12.4	1.008	1.019	1.021	1.031
3	NiCo	3000	12.5	1.004	1.003	1.021	1.027
4	NiCo	2400	12.4	.998	1.012	1.024	1.032
5	Ni	2390	8.72	.994	1.009	1.016	1.023
6	MgMn	2300	12.3	1.009	1.018	1.016	—
7	MgMn	2300	12.7	1.007	1.017	1.013	1.034
8	MgMn	2000	12.2	1.006	1.019	1.021	1.037
9	MgMn	1900	12.5	1.007	1.019	1.022	1.032
10	Yig	1880	14.7	1.009	1.015	1.034	1.030
11	MgMn	1800	11.9	1.009	1.015	1.021	1.041
12	MgMn	1800	11.8	1.010	1.023	1.020	1.051
13	NiCoAl	1670	10.9	1.003	1.016	1.019	1.031
14	Ni	1500	8.46	1.005	.986	.981	1.029
15	MgMnAl	1500	11.7	1.000	1.014	1.026	—
16	NiCoAl	1400	12.0	.998	1.009	1.025	1.027
17	NiAl	1300	11.0	1.002	1.017	1.031	1.051
18	MgMnAl	1250	11.2	.994	1.013	—	—
19	MgMnAl	1200	11.3	1.000	1.000	1.025	—
20	MgMnAl	1200	10.7	.988	1.011	—	—
21	MgMnAl	1100	10.4	1.000	1.018	—	—
22	MgMnAl	1030	11.2	.989	1.012	—	—
23	MgMnAl	950	9.26	1.002	1.010	—	—
24	MgMnAl	950	11.2	1.002	1.014	—	—
25	MgMnAl	800	10.8	1.000	1.016	—	—
26	NiAl	750	10.1	.999	1.014	1.030	1.049
27	MgMnAl	700	9.60	1.006	—	—	—
28	Hybrid Garnet	670	14.1	1.005	1.003	—	—
29	MgMnAl	600	11.2	1.006	—	—	—
30	MgMnAl	500	10.8	.997	—	—	—
31	NiAl	440	8.06	1.000	1.020	—	—
32	NiAl	350	8.20	1.007	1.006	—	—

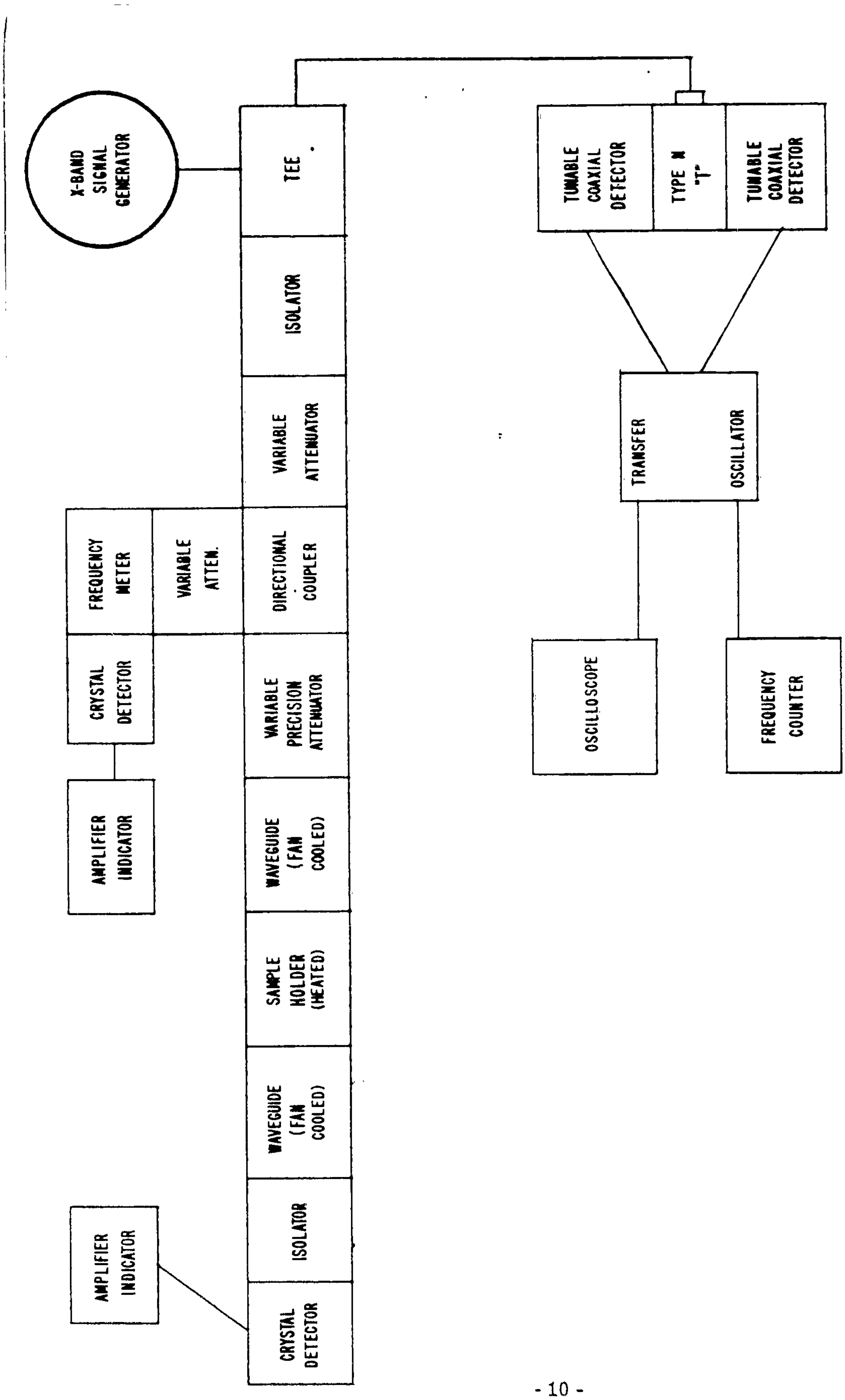
*Commercial Values

$$\text{Ratio} = \frac{K' \text{ at given temperature}}{K' \text{ at } 25^\circ C}$$

TABLE II
Tan δ AS A FUNCTION OF TEMPERATURE

Sample	Composition	$4\pi M_s$*	25°C	100°C	150°C	200°C	250°C
1	Ni	3300	.0137	.0205	.0318	.0447	.0715
2	NiCo	3150	.0011	.0006	.0008	.0007	.0009
3	NiCo	3000	.0013	.0008	.0006	.0007	.0075
4	NiCo	2400	.0001	.0004	.0006	.0012	.0022
5	Ni	2390	.0009	.0006	.0005	.0009	.0020
6	MgMn	2300	.0002	.0001	.0003	.0006	——
7	MgMn	2300	.0001	.0001	.0004	.0012	.0020
8	MgMn	2000	.0004	.0002	.0007	.0011	.0032
9	MgMn	1900	.0001	.0001	.0002	.0002	.0011
10	Yig	1880	.0007	.0006	.0006	.0006	.0006
11	MgMn	1800	.0004	.0013	.0025	.0034	.0096
12	MgMn	1800	.0029	.0076	.0149	.0194	.0393
13	NiCoAl	1670	.0007	.0004	.0002	.0001	.0001
14	Ni	1500	.0014	.0018	.0011	.0017	.0021
15	MgMnAl	1500	.0001	.0003	.0007	.0017	——
16	NiCoAl	1400	.0005	.0005	.0006	.0007	.0011
17	NiAl	1300	.0043	.0071	.0106	.0165	.0244
18	MgMnAl	1250	.0001	.0002	.0005	——	——
19	MgMnAl	1200	.0009	.0003	.0006	.0011	——
20	MgMnAl	1200	.0008	.0016	.0027	——	——
21	MgMnAl	1100	.0009	.0008	.0013	——	——
22	MgMnAl	1030	.0001	.0002	.0005	——	——
23	MgMnAl	950	.0002	.0003	.0005	——	——
24	MgMnAl	950	.0002	.0001	.0002	——	——
25	MgMnAl	800	.0001	.0002	.0004	——	——
26	NiAl	750	.0002	.0003	.0008	.0006	.0002
27	MgMnAl	700	.0004	.0003	——	——	——
28	Hybrid Garnet	670	.0014	.0011	.0009	——	——
29	MgMnAl	600	.0001	.0001	——	——	——
30	MgMnAl	500	.0003	.0005	——	——	——
31	NiAl	440	.0004	.0007	.0013	——	——
32	NiAl	350	.0003	.0007	.0004	——	——

*Commercial Values



BLOCK DIAGRAM OF TEST EQUIPMENT

FIG. I

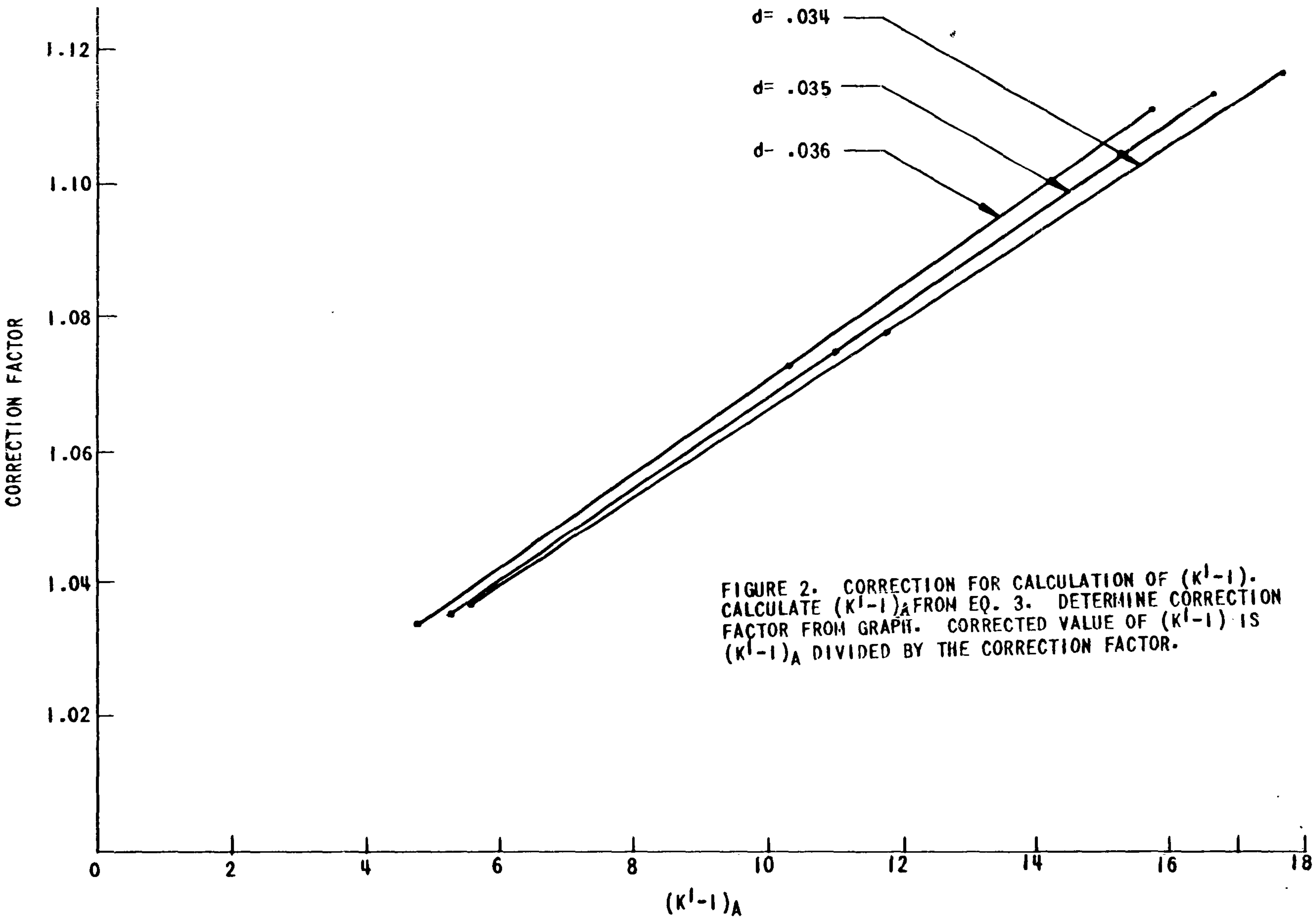


FIGURE 2. CORRECTION FOR CALCULATION OF $(K^{I}-1)$. CALCULATE $(K^{I}-1)_A$ FROM EQ. 3. DETERMINE CORRECTION FACTOR FROM GRAPH. CORRECTED VALUE OF $(K^{I}-1)$ IS $(K^{I}-1)_A$ DIVIDED BY THE CORRECTION FACTOR.

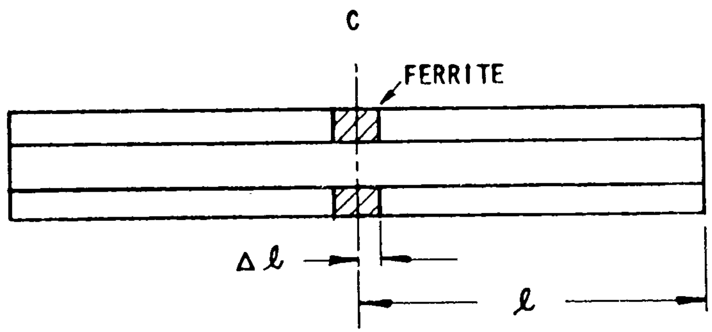
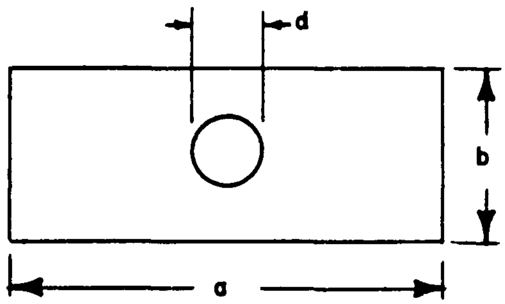
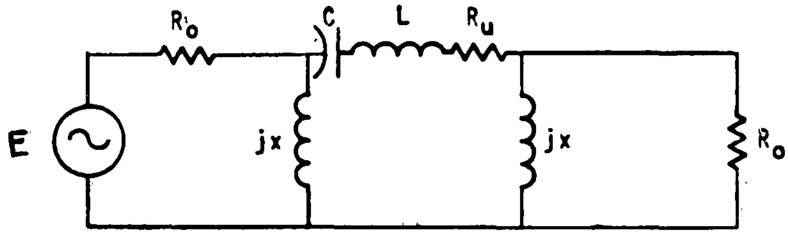


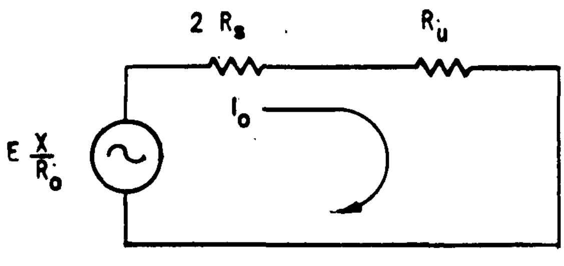
FIGURE 3 FERRITE SAMPLE IN COAXIAL LINE



A IRIS PLATE



B EQUIVALENT CIRCUIT OF WAVEGUIDE CONTAINING CAVITY



C EQUIVALENT CIRCUIT OF CAVITY AT RESONANCE

FIGURE 4 IRIS PLATE AND EQUIVALENT CIRCUITS

IDENTIFICATION OF SAMPLES

Sample Nr.	Company	Number
1	Raytheon	R-161
2	Motorola	MO-52
3	Raytheon	R-191
4	Trans-Tech	TT2-100
5	Motorola	MO-42
6	Raytheon	R-151
7	Motorola	MO-22
8	Kearfott	MGM
9	Trans-Tech	TT-390
10	Motorola	MO-12
11	General Ceramics	R-1
12	General Ceramics	R-4
13	Trans-Tech	TT2-118
14	Kearfott	N40
15	Trans-Tech	TT1-105
16	Trans-Tech	TT2-115
17	Kearfott	AN-20
18	Motorola	MO-112
19	General Electric	36 L
20	General Electric	42 H
21	General Ceramics	R-5
22	Motorola	MO-92
23	General Electric	36 H
24	General Electric	42 L
25	Motorola	MO 32
26	Kearfott	AN 25
27	General Ceramics	R-6
28	Motorola	MO-62
29	Trans-Tech	TT-414
30	Trans-Tech	TT1-103
31	Trans-Tech	TT2-113
32	Kearfott	AN 50

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DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES AT ELEVATED TEMPERATURES by Thomas Collins, Isidore Bady, April 1962, 13 p. incl. illus. tables, 3 refs.
(USASRDL Technical Report 2273)
(DA Task 3A99-15-001-01) Unclassified Report

Measurements were made of the real part of the dielectric constant and loss tangent of 32 commercial ferrites at x-band at temperatures from 25°C to 250°C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the diameter and real part of the dielectric constant. For a sample diameter of 35 mils, the correction ranged from 4 to 10% for dielectric constants of 7 to 16 respectively. Expressions were also derived for the correction due to the contribution of the irises and metal losses to the cavity Q, since the resonant frequency of the cavity changed when a sample was introduced. The accuracy in the measurement of the real part of the dielectric constant if ± 3%, where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005.

1. Dielectric Properties
2. Microwave Ferrites
3. Temperature Effects
4. Perturbation Correction

I. Collins, T.
Bady, I.
II. Army Signal Research and Development Laboratory, Fort Monmouth, N. J.
III. DA Task 3A99-15-001-01

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